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Improvement of Method for Experimental Determination of Flutter Speed by Parameter Identification

Final Report

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Introduction

The method investigated in the current research work is based on the identification of the equations of motion during test flights, followed by the solution of these identified equations to numerically compute the flutter dynamic pressure. The current research work is aimed at overcoming two main difficulties which arise when:

1. A continuous system is truncated into a system with a finite number of degrees of freedom.

2. The desired range of frequencies is wide. In the latter case, numerical difficulties occur that can only partly be overcome by giving relatively more weight to the high frequency modes.

In the following, results pertaining to the above first point will be presented under section entitled "Truncation Effects", and results pertaining to the above second point will be presented under section entitled "Frequency Range Effects". The numerical example used herein is identical to the one used in Ref. 1 (it consists of a continuous simply supported beam). It is further assumed that the object of the identification procedure is to identify the beam's first seven modes.

Truncation Effects

Table 1 shows the effects of truncation on the identified results for different values of damping coefficients, using exact responses (uncorrupted by any measurement errors). It is found that by increasing the number of sensors (i.e. the number of measurement points), while giving linear frequency weighting to the equations, the above truncation errors are virtually eliminated. Such an example is shown in Table 2 where 7 modes are identified using up to 14 measurement points. Table 3 shows results obtained for different values of damping coefficients ζ, confirming the improvements previously described. The conclusions reached are that if n modes need be identified, it is recommended to use $2n$ mesurement points.

Frequency Range Effects

The frequency range effects manifest themselves when the measured responses are contaminated with random measurement errors, as shown in Table 4, where errors of up to 678 percent can be observed. All attempts to consistently overcome these errors, based solely on the above identification method, including variants like the Total Least Squares (TLS) and the mixed LS-TLS methods, failed to yield any improvements. It was therefore necessary to seek a reformulated identification procedure. This latter procedure assumes that the experimental responses corresponding to a set of known frequencies is available from measurements. In addition, initial estimates for the coefficients of the equations to be identified are available from the current identification procedure. On this basis, and as a final identification stage, a target function is defined which involves the differences between the measured and the calculated responses, with the equation coefficients serving as design variables. An optimization procedure is then applied which minimizes the differences between these responses by modifying the estimated coefficients of the equations. The problem has been formulated mathematically, an optimizer routine has been adapted to the problem at hand, and a computer algorithm written. At present stage, gradients of the target function are computed by finite differences and therfore, computing time is excessively long. A sample result is shown in Table 5 under the heading "Optimizer". For comparison purposes, the normal LS results, and the mixed LS-TLS results are also presented. As can be seen, the optimizer results lead to a dramatic reduction in errors at the expense of very long computation times. However these latter times can drastically be reduced once analytical derivatives, and possibly second derivatives, of the target function are formulated and incorporated into the method.

Final Remarks

The optimizer method holds great promise and further work should be done to bring its potential to fruition.

References

1. Nissim,E., and Gilyard, G.B., "Method for Experimental Determination of Flutter Speed by Parameter Identification," NASA TP-2923, June 1989.

Table 1: Effect of Identifying First 7 modes of a System With 36 Modes on the Accuracy of Identified Frequencies and Dampings. Exact Responses Measured at 7 Points Along the Beam.
(ngeneq=36, ndisp=7, nrand=0, derv=1, linfreq=1)

	$\zeta = 0.3$		$\zeta = 0.03$		$\zeta = 0.003$	
Mode No.	Frequency Error %	Damping Error %	Frequency Error %	Damping Error %	Frequency Error %	Damping Error %
1	1.60	81.9	2.52	172.	0.31	46.2
2	1.84	13.7	0.46	8.11	0.05	-2.27
3	-0.44	4.21	0.16	-2.11	0.02	-4.36
4	-0.16	1.15	0.01	-0.55	0.0	-0.89
5	0.17	28.1	-0.10	-15.3	-0.01	-22.5
6	2.19	-6.77	0.09	1.66	0.01	2.65
7	-0.25	18.0	-0.07	5.28	-0.01	4.48

Table 2: Effect of Increasing Number of Measurement Points on the Accuracy of Identified Frequencies and Dampings. Responses Generated by a 36 Modes System. First 7 Modes Identified. Exact Measurements and Exact Mode Shapes Assumed. (ngeneq=36, $\zeta = 0.3$, nrand=0, modal=1, linfreq=1)

	$ndisp = 7$		$ndisp = 8$		$ndisp = 9$	
Mode No.	Frequency Error %	Damping Error %	Frequency Error %	Damping Error %	Frequency Error %	Damping Error %
1	1.60	81.9	-2.39	-40.9	1.06	28.8
2	1.84	13.7	-1.80	-11.8	1.46	8.10
3	-0.44	4.21	0.41	-2.62	-0.25	1.92
4	-0.16	1.15	0.34	-2.57	-0.20	1.83
5	0.17	28.1	0.79	-7.84	-0.27	5.77
6	2.19	-6.77	0.47	-1.32	-0.67	1.91
7	-0.25	18.0	1.01	-17.4	-0.37	6.39
	$ndisp = 10$		$ndisp = 14$			
Mode No.	Freq. Error %	Damp. Error %	Freq. Error %	Damp. Error %		
1	-1.21	-21.8	-0.34	-6.14		
2	-1.32	-7.03	0.32	1.51		
3	0.11	-0.81	0.03	-0.21		
4	0.16	-1.25	-0.02	0.16		
5	0.31	-4.21	0.07	-1.06		
6	0.51	-1.33	0.0	0.01		
7	0.25	-3.72	0.03	-0.36		

Table 3: Effect of Identifying First 7 Modes of a 36 Modes System on the Accuracy of Identified Frequencies and Dampings. Exact Responses Measured at 14 Points Along the Beam. Exact Mode Shapes Assumed Known.
(ngeneq=36, ndisp=14, nrand=0, derv=1, linfreq=1, modal=1)

	$\zeta = 0.3$		$\zeta = 0.03$		$\zeta = 0.003$	
Mode No.	Frequency Error %	Damping Error %	Frequency Error %	Damping Error %	Frequency Error %	Damping Error %
1	-0.34	-6.14	-0.2	-12.4	-0.02	-3.57
2	0.32	1.51	0.06	0.82	0.01	-0.34
3	0.03	-0.21	-0.01	0.13	0.0	0.23
4	-0.02	0.16	0.0	-0.18	0.0	-0.25
5	0.07	-1.06	0.01	0.56	0.0	0.86
6	0.0	0.01	0.0	0.0	0.0	-0.01
7	0.03	-0.36	0.0	0.1	0.0	-0.1

Table 4: Effect of Identifying First 7 modes of a 36 Modes System With 5 Percent Measurement Errors on the Accuracy of Identified Frequencies and Dampings. Responses Measured at 14 Points Along the Beam. No Knowledge of Exact Mode Shapes is Assumed.
(ngeneq=36, ndisp=14, nrand=1, ranpcent=5, derv=1, linfreq=1, $n = 14 \Rightarrow 7$)

	$\zeta = 0.3$		$\zeta = 0.03$		$\zeta = 0.003$	
Mode No.	Frequency Error %	Damping Error %	Frequency Error %	Damping Error %	Frequency Error %	Damping Error %
1	2.96	-11.1	1.85	-32.2	1.41	-678
2	0.72	5.86	0.56	-11.5	0.48	-35.4
3	0.36	-1.41	0.06	-1.06	0.07	-5.81
4	-0.07	0.83	0.02	-0.45	0.01	-3.48
5	-1.11	-3.22	-0.26	0.34	-0.17	2.90
6	-0.05	0.29	-0.02	0.25	-0.01	-0.56
7	-2.06	2.26	-0.13	-0.34	-0.10	-1.29

Table 5: Comparison between the LS, the mixed LS-TLS, and the Optimizer Methods on the Accuracy of Identified Frequencies and Dampings. 7 Mode System With 5 Percent Measurement Errors With Responses Measured at 14 Points Along the Beam. $\zeta = 0.003$. No Knowledge of Exact Mode Shapes is Assumed.

(ngeneq=36, ndisp=14, nrand=1, ranpcent=5, derv=1, linfreq=1, $n = 14 \Rightarrow 7$)

	LS		Mixed LS-TLS		Optimizer	
Mode No.	Frequency Error %	Damping Error %	Frequency Error %	Damping Error %	Frequency Error %	Damping Error %
1	1.41	-678	1.41	-679	0.00	-1.54
2	0.48	-35.4	0.48	-35.4	0.00	1.31
3	0.07	-5.81	0.07	-5.81	-0.01	1.05
4	0.01	-3.48	0.01	-3.47	0.00	0.26
5	-0.17	2.90	-0.17	2.91	0.00	-2.38
6	-0.01	-0.56	-0.01	-0.56	0.00	-0.61
7	-0.10	-1.29	-0.10	-1.28	0.00	-1.49